Daya Bay from Commissioning to Physics

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KA13 DOE Review

Outline

Overview

Progress
- Muon system design & capabilities
- Software
- Simulation
- Analysis

Plans
- Analysis
- Operations
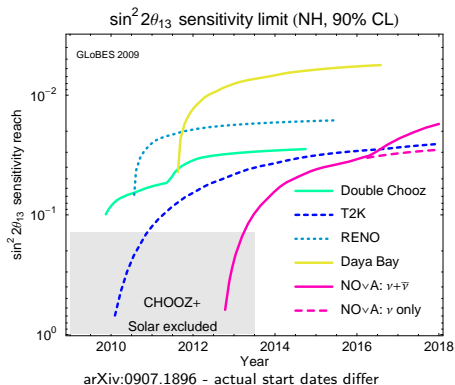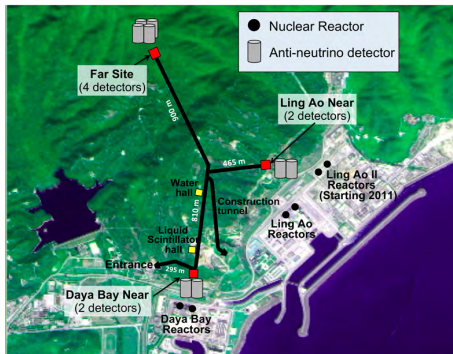- RACF
- Potential branch point

Summary

Overview

The determination of $\sin^2 2\theta_{13}$ is a critical ingredient in the effort to measure leptonic CP violation and neutrino mass ordering.

AD1 Dry Run	6-9/2010
AD2 Dry Run	9/2010
Daya Bay near site	Fall 2011
All sites	Fall 2012

$\sin^2 2\theta_{13}$ sensitivity limit (NH, 90% CL)

GLoBES 2009

- Double Chooz
- T2K
- RENO
- Daya Bay
- NOvA: $\nu + \bar{\nu}$
- NOvA: ν only

CHOOZ+
Solar excluded

arXiv:0907.1896 - actual start dates differ

With a $\sim$6 month run, Daya Bay will have the best $\sin^2 2\theta_{13}$ sensitivity in the history of the universe.

Progress (2008-2010)

Muon system design & capabilities

▶ Initial muon system design and simulation made possible by BNL LDRD funds

▶ Based on simulation, the design is robust against reasonable loss of PMTs and occlusion of Cherenkov light, and

▶ Is able to reconstruct most muon trajectories through the water pool with $\sim$50cm resolution despite $< 1\%$ photocathode coverage

Far water pool in simulation
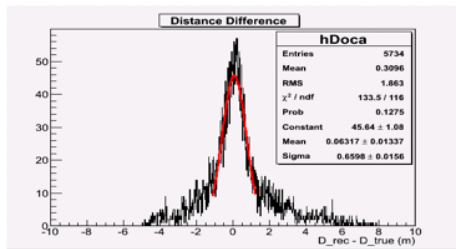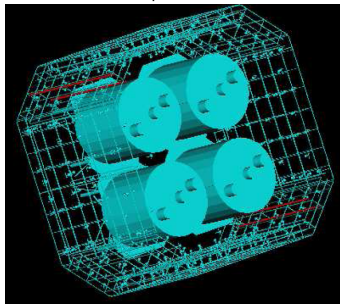
Distance of closest approach. Recon - True (m)

Software

- ▶ B.Viren was critical in the decision process and implementation of the Gaudi software framework.
- ▶ `dybinst`: Easy-to-use software installation system developed by Viren.
  - ▶ Works on all collaboration platforms, including laptops.
  - ▶ Likely to be used by LBNE, under consideration by MINERνA
  - ▶ Facilitates automated build & installation system
- ▶ Postdocs Z.Wang, L.Whitehead validated Gaudi-based software (NuWa)
- ▶ Viren, Wang, Whitehead have helped lead numerous software tutorials
- ▶ D.Jaffe organized week-long software workshop in April 2008
- ▶ Offline Documentation Portal maintained at BNL
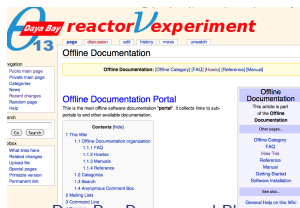
Simulation

▶ Jaffe, Viren, Wang created and implemented extensions to Gaudi to take into account the asynchronous nature of Daya Bay data

▶ Viren developed GenDecay to incorporate the latest nuclear decay data from NNDC

▶ Wang create MuonProphet to speed simulation of muons and cosmogenically produced isotopes

▶ Jaffe organized production of large samples of simulated data for the collaboration

▶ Whitehead performed θ_{13} sensitivity studies

▶ Jaffe, H.Tanaka, Viren working with PanDA [1] team to develop production capabilities

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[1] Production and Distributed Analysis system supported by BNL Physics Application Support Group
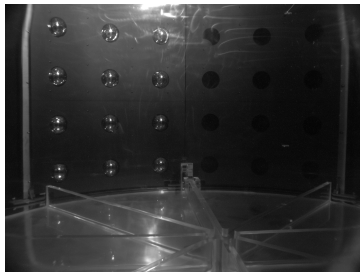
Analysis

Milestone	Date
Mini-dry run	December 2009 - January 2010
AD1 Dry Run	June - September 2010
AD2 Dry Run	September 2010
Possible Dry Run in EH1	Spring 2011
Daya Bay near site ready for data	Autumn 2011
Far site ready for data	Autumn 2012
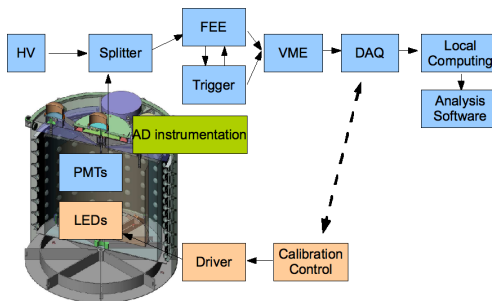
AD Dry Run ≡ End-to-end system test (PMT→offline) in **dry** detector in SAB.

Mini-dry run (Dec09-Jan10)
Partially instrumented AD in SAB.

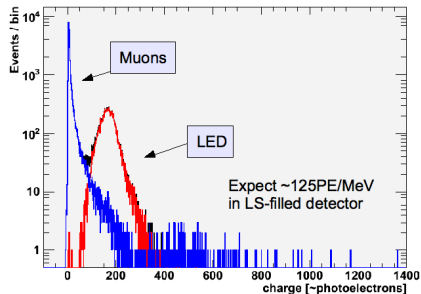*AD camera image with visible light LEDs*

Muons

LED

Expect ~125PE/MeV
in LS-filled detector

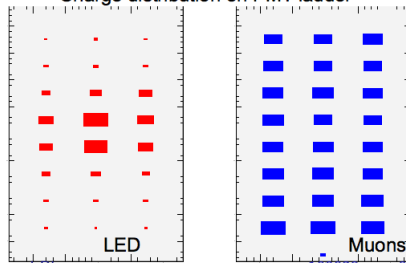Charge distribution on PMT ladder

LED

Muons

Mini-dry run provided analysis
experience & lead to improvements in

- ▶ Automated calibration control,
- ▶ PMT-to-PMT noise,
- ▶ electronics/trigger firmware,
- ▶ DAQ software, &
- ▶ data transfer.

AD1 Dry Run (Jun-Sep10)

Capabilities of AD1 Dry Run system

- ▶ Fire calibration LEDs along 3 vertical axes
- ▶ 192 8"-PMTs & six 2" calibration PMTs
- ▶ Electronics digitizes signals
- ▶ Multiplicity, charge sum, external, random triggers
- ▶ DAQ records data
- ▶ Online and offline data analysis with NuWa
- ▶ Run ∼continuously for days
- ▶ Automated data transfer to LBNL & IHEP
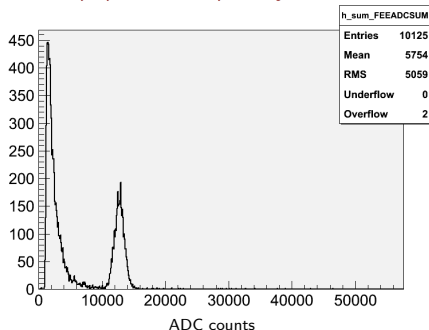- ▶ Double-pulse LEDs to mimic $\bar{\nu}_e p \rightarrow e^+ n$ (IBD)
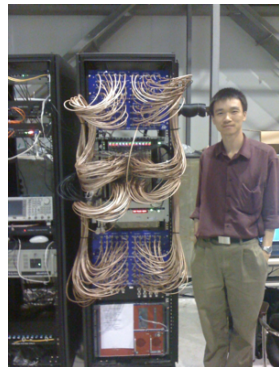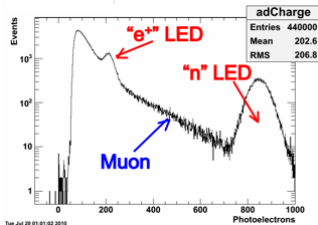
Zhe Wang is the Dry
Run Offline Coordinator

AD1 Dry Run online & offline monitoring
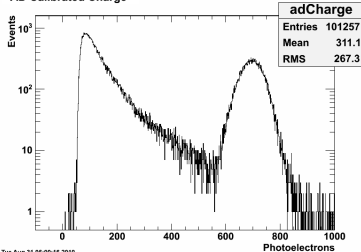Run 2015: $\sim$1 minute, 500 Hz LED, ACU B Z axis scan.

Online monitoring of one-tenth of all triggers
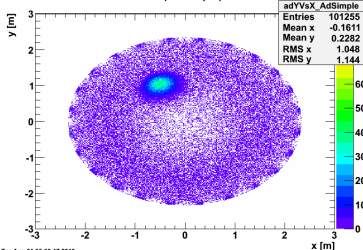
AD1 Dry Run unexpected data features

Problems revealed by offline analysis (and bench tests):

- ▶ LED instability   *Scint. source under development*
- ▶ Time offset between electronics boards   *AD2 Dry Run*
- ▶ Muon data rate, Cherenkov light pattern from acrylic not consistent
  with simulation   *Under study*
- ▶ NuWa (Offline analysis software) too slow   *Improved*
- ▶ PMT "flashers"   *Under study*
- ▶ Triggers due to noise   *AD2 Dry Run*

Many analysis results available at analysis workshop mid-July 2010

Some features:

- ▶ AD response to LED scan along central
  axis uniform to ∼8%

- ▶ AD double-pulse response satisfactory
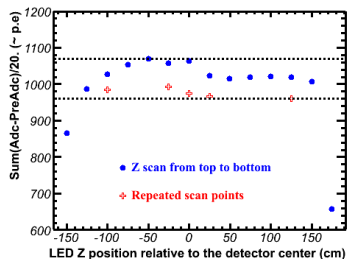
AD2 Dry Run (20-30 Sept 2010)

Goals (Focus on hardware performance):

- ▶ PMT performance (gain, dark rate, stability)
- ▶ System stability
- ▶ Calibration system performance (ACU motion, LED efficiency, stability)

Preliminary results:

- ▶ The electronics hardware was modified to reduce ADC non-linearity observed in AD1 Dry Run.
- ▶ Comparison of multiplicity trigger rate in AD2 with AD1 with the modified electronics shows consistent performance of AD pair.
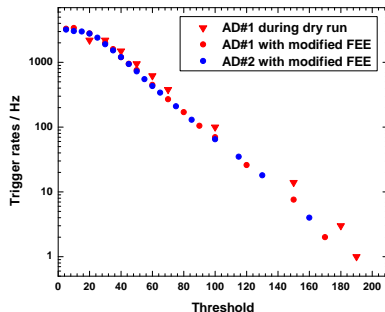
Plans (2011-2013)

Analysis

The Collaboration formed a four-person Analysis Coordination Committee in Jan. 2010. Jaffe served as chair from Jan. through June 2010.
ACC activities:

- ▶ Ensuring reactor information is available in offline database. Requires negotiation with NPP.
    1. Thermal power
   2. Simulation data for fission fractions.
    3. Neutron flux
- ▶ Formation of analysis task forces.
- ▶ Organization production of large MC sample corresponding to ~ 3 months of Daya Bay near data.
- ▶ Long-term analysis plan
- ▶ Formation of working groups (*i.e.*, calibration, production, etc.)

Analysis task forces

- ▶ Dry Run task forces
  - ▶ AD uniformity (Zhe Wang, BNL)
  - ▶ Double-pulse response (S.Jetter, IHEP)
  - ▶ Dynamic range (Zhimin Wang & H.Lu, IHEP)
  - ▶ PMT calibration (P.Ochoa, LBNL)
- ▶ Survey information (H.Band, UW & L.Wen, IHEP)
- ▶ Detector mass (C.Lewis, UW)
- ▶ As-built water pool (Q.He, Princeton)
- ▶ As-built RPC (J.Xu, IHEP)
- ▶ RPC electronics simulation (Z.Ning, IHEP)

Production of large Daya Bay near site MC sample

▶ Preliminary study on ∼6 hour sample with single AD simulation including IBD and radioactivity.

▶ Results presented at UW Analysis Workshop (May 10)
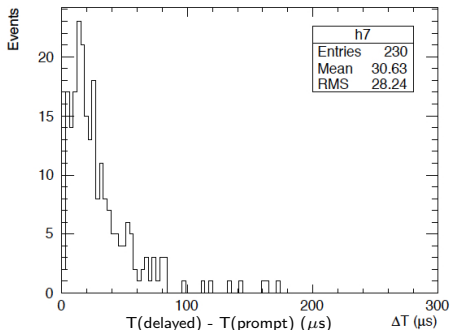
▶ Secondary studies on ∼3 day sample with Daya Bay near site simulation including IBD, radioactivity, cosmic muons and cosmogenically produced isotopes.

▶ Results presented at Weihai Analysis Workshop (July 2010)
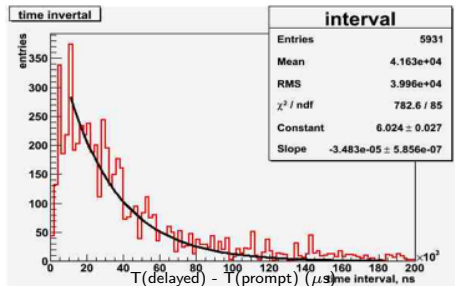
Current Daya Bay analysis plan

1. We expect to have several, competing $\sin^2 2\theta_{13}$ analyses with differing methodologies that will provide internal cross-checks and ensure the robustness of the result.

2. To facilitate comparison of these analysis, we have agreement on
   - The use of common algorithms to provide the basic calibrated quantities,
   - The establishment of data quality criteria to select "good runs", and
   - All analysis code being in our software repository.

3. The appropriateness of a "blind analysis" is under discussion.

- Dry Runs have provided valuable experience in collaborative analysis and in refining our plans.

- The Daya Bay near site data will allow us to test details of our analysis and operation plans (next pages).

Current BNL analysis plan

- ▶ Measure the "fast neutron" background. (Most uncertain of the expected backgrounds.)
    - ▶ Expand on work and studies by Littenberg, Jaffe and former postdoc K.Zhang.
    - ▶ Exploits muon system expertise.
    - ▶ Engages University groups of muon system.
- ▶ Develop and refine calibration algorithms. Expand on current work in
    - ▶ Charge calibration (Wang)
    - ▶ Time calibration (Ling)
    - ▶ Non-linear energy response of liquid scintillator (Whitehead). Draw on LS expertise of BNL Chemistry colleagues.
- ▶ Contribute to large-scale MC production.
    - ▶ Utilize extensions to Gaudi created and implemented by Jaffe, Viren, Wang.
    - ▶ Exploit simulation tools developed by Viren, Wang.
    - ▶ Exploit production expertise of Jaffe, Tanaka, Viren. Leverage PanDA system of BNL Physics Application Support Group.

Daya Bay near site run operations and goals (1)

The primary goals of initial operations are a fully calibrated muon system and fully calibrated AD pair, followed by verification of muon and AD performance and an extensive study and verification of systematic uncertainties:

1. Measure detector rates and spectra (compare to expectations, identify problems)
2. Verify trigger/DAQ performance
3. Verify offline analysis software, databases and calibration code
4. Full calibration
5. Measure cosmic muon flux
6. Measure reactor neutrino flux and compare to 1st principle calculation
7. Study systematic uncertainties
   7.1 Investigate all AD1,AD2 differences
   7.2 Study neutron energy threshold cut for source and spallation neutrons
   7.3 Measure relative distance to reactors of AD1 and AD2

# Daya Bay near site run operations and goals (2)

8. Additional studies
    8.1 Look for discrepancies in the neutron capture time between ADs, and between spallation vs. calibration source (AmC) neutrons.
    8.2 Dissect singles spectrum (energy and position). Identify possible variations in radioactive contamination in AD modules. (It may be possible to mitigate contamination in successive ADs).
    8.3 Measure energetic (6 MeV to 30 MeV) backgrounds. Verify they are consistent with expectations from cosmogenic decays, neutron capture on steel, and fast neutrons.
    8.4 If sufficient Bi-Po backgrounds exist, use them to measure scintillator quenching.
    8.5 Examine singles spectrum for alpha peaks in the 0.2 to 1 MeV region. Use alpha rates to constrain possible alpha-n coincidence backgrounds.
    8.6 Invert prompt/delayed anti-neutrino event selection and verify that results are consistent with expectations.

RACF: RHIC-ATLAS Computing Facility

- ▶ We are contributing to RACF, from Daya Bay project and operations funds, in order to maintain on-disk storage of a 1/10-reduced data set in RACF at BNL.
- ▶ Rely on storage and availability of full data set at LBNL (PDSF).
- ▶ Provides computing resources for the Daya Bay collaboration. Currently five of twelve Daya Bay RACF users are non-BNL.
- ▶ We are leveraging BNL expertise to develop a production system for the collaboration.

Potential branching point
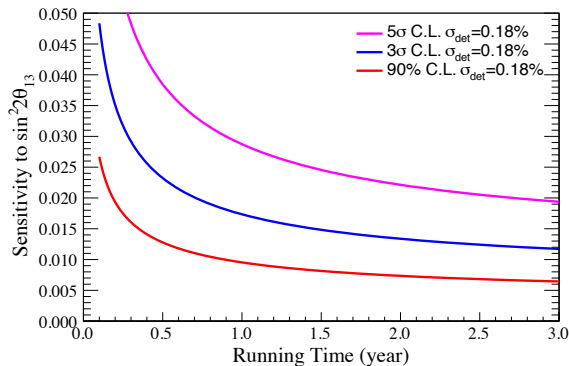
With one full year of data, if $\sin^2 2\theta_{13} > 0.03$, Daya Bay would be able to make a $\sim 5\sigma$ measurement.

- ▶ Potential branching point that may affect the transition of funding from KA13 to KA11 to support BNL scientists for LBNE.
- ▶ *Could* occur near the end of 2013.

Summary

- ▶ We have made good progress towards the Daya Bay measurement of $\sin^2 2\theta_{13}$, a critical ingredient in the determination of leptonic CP violation and neutrino mass ordering.
- ▶ BNL has made important contributions to software, simulation and analysis.
- ▶ BNL is well-placed for a major contribution to the rapid analysis of neutrino data.
- ⋆ We have planned for a modest increase in staff given our significant responsibilities on Daya Bay and LBNE.
- ⋆ The convergence of installation, commissioning and initial operations will increase travel demands in FY11-13.
- ⋆ The transition of staff from Daya Bay to LBNE in the coming years will require a transfer of funds from KA13 to KA11.